Physiologic Responses to Weight Lifting in Coronary Artery Disease

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This study assesses the safety of and physiologic responses to maximal repetition, dynamic, resistive weight lifting at 40, 60, 80 and 100% of maximal voluntary contraction compared with aerobic exercise using a maximal treadmill exercise test. Twelve men with coronary artery disease exercised to fatigue at 4 stations (overhead press, biceps curl, quadriceps extension and supine press). The electrocardiogram was monitored continuously. Heart rate and systolic and diastolic blood pressures (by sphygmomanometer) were measured at rest and during peak exercise. No symptoms or electrocardiographic evidence of ischemia occurred with weight lifting, whereas 5 of 12 patients had ischemic ST-segment depression (≥1 mm) with the treadmill. No significant arrhythmia occurred with either activity. Mean peak heart rates with all lifts were less (range 74 to 92 beats • min⁻¹; p ≤ 0.05) than with the treadmill (157 beats • min⁻¹). Peak systolic blood pressures were similar, whereas peak diastolic blood pressures were greater with all lifts (range 93 to 117 mm Hg; p ≤ 0.05) than with the treadmill (79 mm Hg). Peak rate pressure product was greater with the treadmill than with all lifts (p ≤ 0.05). Diastolic time interval from the electrocardiograph was shorter with the treadmill (0.154 second) than with all lifts (range 0.232 to 0.448 second; p ≤ 0.05). Diastolic pressure-time index was greater with all lifts than with the treadmill (p ≤ 0.05). The ratio of the diastolic pressure-time index to rate pressure product, an indirect estimate of the balance between myocardial oxygen supply and demand, was greater for all lifts (range 0.214 to 0.262 second; p ≤ 0.05) than for the treadmill (0.074 second). Thus, estimated myocardial oxygen supply-to-demand balance appears more favorable with maximal repetition weight lifting than with maximal treadmill exercise.

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Cardiac patients generally have been cautioned to avoid heavy resistive exercise, because of the potentially deleterious effects of such activity. Early reports found marked increases in left ventricular pressures and arrhythmias with isometric exercise in patients with coronary disease. However, more recent studies in coronary patients documented the safety of lower intensity isometric and dynamic, resistive exercise, which were unassociated with clinical or electrocardiographic evidence of myocardial ischemia or significant arrhythmias.

Despite 2 reports that investigated higher intensities of weight lifting (a dynamic, resistive [not static] activity) in coronary patients, there is a paucity of information regarding higher intensity lifting in such patients. The purposes of this study were to assess the safety, hemodynamic effects and estimates of myocardial oxygen supply and demand resulting from maximal repetition weight lifting at 40, 60, 80 and 100% of maximal voluntary contraction in stable, aerobically trained, coronary disease patients and to compare their responses during weight lifting to those during maximal treadmill exercise. We hypothesized that lower heart rates and higher diastolic blood pressures would occur with weight lifting and that these would create a more favorable myocardial oxygen supply-to-demand balance than would treadmill exercise.

METHODS

Subjects: Twelve men (age range 34 to 68 years, mean 55 ± 9) volunteered for this research project. Measured maximal oxygen uptake ranged from 20.0 to 43.5 ml • kg⁻¹ • min⁻¹ (mean 29.4 ± 7.4). All subjects had stable, documented coronary artery disease. Seven subjects had a previous myocardial infarction; 2, coronary artery bypass grafts; 1, both an infarction and bypass grafts; and 2, angina with angiographically documented coronary artery disease. Cardiac medications remained constant throughout the study in all subjects. Four subjects were receiving β blockers; 4, calcium antagonists; and 2, nitrates.

All subjects had been participating in a cardiac rehabilitation program for at least the preceding 4 months (mean 24 ± 10). The exercise component of the rehabilitation program consisted of both warm-up and cool-down periods of calisthenics and stretching, and a 30- to 40-minute period of dynamic aerobic activities: walking, jogging, and stationary cycling or rowing or both. No subject had recent weight lifting experience.

Before beginning the study, all procedures were fully demonstrated, the risks and benefits of all activities were fully explained, and informed consent was obtained.
Prior approval was obtained from the university's human subject's review committee.

**Maximal treadmill test:** Before entry in the study, all subjects performed a maximal treadmill exercise test following the continuous ramp protocol of Dresendorfer and Amsterdam,\(^1\) where grade increases at the rate of 2.25%/min at the patient's self-selected walking or running speed. Symptom-limited maximal oxygen uptake was determined on-line (Digital Equipment Corp., LSI-11/2), as previously described by Harris and Holly.\(^1\) Systolic and diastolic blood pressures were measured indirectly by a sphygmomanometer at rest, and during each minute of exercise and recovery. Heart rate was recorded on a Hewlett-Packard 1500A electrocardiograph at rest, and during each minute of exercise and recovery. The electrocardiogram was monitored continuously. An ischemic response was defined as ≥ 1 mm ST depression at 80 ms.

**Maximal repetition weightlifting:** All subjects performed the maximal number of repetitions they could at 40, 60, 80 and 100% of maximal (voluntary) contraction, which was defined as the maximal weight the subject could lift once within a 1- to 2-second period without straining or Valsalva. If the subject could not complete the lift within the allotted time or appeared to be straining, the weight was reduced, and maximal contraction was reassessed at this lower weight.

Maximal contraction was measured using free weights and a weight bench for the 4 exercises that comprised the study: supine (bench) press, seated (military) overhead press, seated biceps curl and seated quadriceps extension. Both legs were used to perform the quadriceps extension, whereas only the dominant (right) arm was used to perform the 3 upper body lifts so that blood pressure could be measured in the nondominant arm during the actual lifting motion. Timing of this measurement is critical because both systolic and diastolic blood pressures rapidly return toward resting values immediately on cessation of lifting.\(^1\) Therefore, blood pressure was always measured during the last repetition of each lift, and completed before the end of the lift. (When lifting at 100% maximal contraction, the cuff was pumped up before the lift began and bled off during the lift.) The heart rate and electrocardiogram were continuously monitored and recorded during all lifts on a Quinton 631A electrocardiograph. Blood pressure was measured indirectly with a sphygmomanometer by the same technician throughout the project. The product of heart rate and systolic blood pressure determined the rate-pressure product.\(^1\) The product of diastolic blood pressure, diastolic time interval and heart rate determined the diastolic pressure-time index.\(^1\) The diastolic time interval was measured over 4 consecutive beats from the end of the T wave on the electrocardiogram to the onset of the next QRS complex. All subjects were instructed on, and practiced, proper and safe lifting techniques before data collection.

Maximal contraction was determined as follows: A reasonable initial weight was estimated from pilot experiments with healthy, middle-aged adults. After a 10-minute warm up of stretching, walking and performing 5 repetitions using an unweighted 4.5 kg bar, each subject lifted 3 increasing weights, 1 time each, with the last weight being as close as possible to the maximal contraction. One minute of rest was allowed between each trial to enable heart rate and blood pressure to return to within 10% of resting values. After the third trial, subjects rested 10 minutes to enable muscle fatigue to subside and then lifted a final time for their best estimated maximal contraction. If necessary, additional trials were performed after 10-minute rest periods until a maximal contraction was determined. This procedure was followed in random order on the same day to determine maximal contraction for all 4 exercises.

Subjects returned on 3 additional occasions after determination of maximal contraction at an average interval of 11 days between each session to minimize any training effect. On each occasion, they performed each of the 4 exercises at either 40, 60 or 80% of the respective maximal contraction. The percent maximal contraction for each exercise was randomized over the 3 visits in a Latin-square array, with the exception of the supine press, which was always performed last because of its possible interference with the performance of the overhead press (a lift that more closely approximates overhead lifting motions). The order of the remaining 3 lifts was selected at random. Each session began with the same warm up as previously described for determination of maximal contraction. Subjects performed the upward and downward motions of each lift to the beat of a metronome, with cadence set at 60 beats/min. Criteria for termination of any lift included: fatigue, as evidenced by inability to follow the beat of the metronome; any signs of straining or Valsalva; a maximum of 60 repetitions (due to time constraints); and signs/symptoms of exertional intolerance. The electrocardiogram was monitored continuously by a physician or registered nurse. For each exercise, heart rate and blood pressure were measured at rest, during the performance of the final repetition and at 30 seconds of recovery. Adequate

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**TABLE I Amount of Weight (Wt) Lifted and Maximal Number of Repetitions (Reps) Performed at Various Percentages of Maximal Voluntary Contraction (% MVC)**

<table>
<thead>
<tr>
<th>% MVC</th>
<th>OP</th>
<th>BC</th>
<th>QE</th>
<th>SP</th>
</tr>
</thead>
<tbody>
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<td>Wt (kg)</td>
<td>Reps (no.)</td>
<td>Wt (kg)</td>
<td>Reps (no.)</td>
</tr>
<tr>
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<td>22 ± 3</td>
<td>5 ± 1</td>
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<tr>
<td>100</td>
<td>14 ± 3</td>
<td>1 ± 2</td>
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Values are mean ± SD (n = 12).

BC = biceps curl (1 arm); OP = overhead press (1 arm); QE = quadriceps extension (2 legs); SP = supine press (1 arm).
time between each exercise was allowed for these measurements to return to within 10% of resting values. Subjects were questioned regarding the presence of chest or muscle pain after each exercise.

**Statistics:** Data are presented as mean ± SD. Statistical analyses were performed using the Biomedical Computer Program BMDP2V for analysis of variance with repeated measures. A p value <0.05 was chosen for determining statistical significance.

**RESULTS**

Twelve men performed maximal treadmill tests and maximal number of repetitions for 4 weight lifts at 40, 60, 80 and 100% of maximal contraction. No patient developed chest pain or significant ventricular ectopy during either lifting or treadmill. There were no ischemic electrocardiographic signs with lifting, whereas 5 of 12 patients developed ischemic changes during maximal treadmill exercise, and 1 treadmill test was terminated prematurely at near maximal exertion for >2 mm ST depression. Resting rate-pressure product was similar in both conditions (treadmill 9,648 ± 2,141 mm Hg ∙ min⁻¹ vs lifting 9,051 ± 2,182 mm Hg ∙ min⁻¹).

Table 1 lists the maximal number of repetitions performed, and the amount of weight lifted, for each lift at each percent maximal contraction. The number of repetitions was inversely related to percent maximal contraction, as expected.
maximal contraction, but was only significantly so for the supine press (Figure 4).

When estimates of myocardial oxygen supply were compared with those of myocardial oxygen demand (Figure 5), all lifts yielded significantly higher ratios than did treadmill exercise, but did not differ among themselves.

**DISCUSSION**

This study revealed no adverse effects in 12 stable, aerobically trained patients with coronary artery disease during maximal repetition weight lifting at 40, 60, 80 and 100% maximal contraction. Furthermore, there were considerable differences between maximal, dynamic, resistive weight lifting and maximal, dynamic, aerobic exercise. 

**FIGURE 3.** Peak diastolic blood pressure during maximal treadmill exercise (TM) and maximal repetition weight lifting at 40, 60, 80 and 100% of maximal (voluntary) contraction for following lifts: overhead press (OP), biceps curl (BC), quadriceps extension (QE) and supine press (SP). Values are mean ± 1 SD (n = 12). Asterisk, treadmill exercise is different from all weight lifts (p < 0.05). Dagger, 100% maximal contraction is different from 40, 60 and 80% for given lift (p < 0.05).

**FIGURE 4.** Peak diastolic pressure-time index during maximal treadmill exercise (TM) and maximal repetition weight lifting at 40, 60, 80 and 100% of maximal (voluntary) contraction for following lifts: overhead press (OP), biceps curl (BC), quadriceps extension (QE) and supine press (SP). Values are mean ± 1 SD (n = 12). Asterisk, treadmill exercise is different from all weight lifts (p < 0.05). Dagger, 100% maximal contraction is different from 40, 60 and 80% for given lift (p < 0.05).

**FIGURE 5.** Ratio of peak diastolic pressure-time index (DPTI) to peak rate-pressure product (RPP) during maximal treadmill exercise (TM) and maximal repetition weight lifting at 40, 60, 80 and 100% of maximal voluntary contraction for following lifts: overhead press (OP), biceps curl (BC), quadriceps extension (QE) and supine press (SP). Values are mean ± 1 SD (n = 12). Asterisk, treadmill exercise is different from all weight lifts (p < 0.05).
treadmill exercise in hemodynamic variables measured noninvasively. These variables suggested a potentially more favorable effect on the myocardial oxygen supply-to-demand balance in maximal lifting than in treadmill exercise.

The absence of symptoms and electrocardiographic abnormalities during lifting in our selected coronary patients is consistent with previous data during submaximal weight lifting. Where 1 session of circuit weight training (10 to 12 repetitions at 40 to 60% maximal contraction), 1 session of weight lifting up to 80% maximal contraction, and a 10 week strength training program (8 to 12 repetitions at 80% maximal contraction) all demonstrated the safety of weight lifting in coronary patients. The present study extends these findings to lifting at 100% maximal contraction and directly compares the hemodynamic responses during maximal repetitive lifting at 40, 60, 80 and 100% maximal contraction with those during maximal treadmill exercise. Although 5 of 12 patients developed ischemic ST-segment abnormalities during maximal treadmill exercise, no signs or symptoms of myocardial ischemia were induced during maximal repetition weight lifting.

There were also considerable differences in various peak hemodynamic responses during lifting compared with during treadmill exercise (Figures 1 to 5). The lower peak rate-pressure product during lifting suggests that myocardial oxygen demand is less during dynamic, resistive lifting than during treadmill (Figure 2). It has been suggested that the factors determining perfusion of the subendocardium can be represented by the area between the aortic and left ventricular pressure curves during diastole. This has been called the diastolic pressure-time index. When it is expressed on a per-minute basis, it is the product of heart rate, diastolic blood pressure, and the time period of diastole. In this noninvasive study, we did not measure left ventricular diastolic pressure; however, it is unlikely that it increased greatly in our subjects, all of whom had adequate ventricular function at rest and had no clinical evidence of depressed ventricular function during exercise. Based on this approach, estimates of subendocardial perfusion were greater during lifting than during treadmill exercise (Figure 4).

The ratio of the diastolic pressure-time index to the tension-time index was previously suggested as an index of myocardial oxygen supply-to-demand balance. Because rate-pressure product has been shown to be a better predictor of myocardial oxygen demand than is tension-time index, the ratio of diastolic pressure-time index to rate-pressure product should also provide a reasonable estimate of myocardial oxygen balance. Figure 5 shows that all lifts yielded significantly more benefits ratios than did treadmill exercise. These results suggest that there is a hemodynamic basis for selected coronary patients to tolerate dynamic, resistive lifting, even at high intensities and with maximal repetitions, because such lifting may maintain an appropriate myocardial oxygen supply-to-demand ratio. No particular percent maximal contraction appeared to confer any advantage in this regard. Rate-pressure product in the various lifts tended to be less at 100% maximal contraction than at other intensities due to the limited time for heart rate and systolic blood pressure to respond during 1 repetition. However, diastolic pressure-time index was also less due to the much lower diastolic blood pressure at 100% maximal contraction than at other intensities. Thus, the ratio of these 2 quantities at 100% maximal contraction was similar to that of the other lifts (Figure 5).

Previous data tend to support our finding that an appropriate ratio exists during lifting in selected coronary patients. For example, circuit weight training at an estimated 40 to 60% maximal contraction yielded lower peak heart rates and systolic blood pressures, and higher diastolic blood pressures than did treadmill exercise. Furthermore, Butler et al showed a slight but significant improvement in some segmental left ventricular wall motion scores when weight lifting was compared with treadmill exercise at the same heart rate.

It is of interest to compare the responses during maximal repetition weight lifting to those of a typical, cardiac rehabilitation, aerobic conditioning session. When we assessed contemporaneous aerobic conditioning records in the 9 of 12 patients for whom data were available, we found that rate-pressure product during maximal repetition weight lifting (range 12,057 to 16,036 mm Hg • min⁻¹; Figure 3) did not differ appreciably from that during typical aerobic conditioning sessions (15,453 ± 3,566 mm Hg • min⁻¹). Because heart rates and blood pressures were most often obtained during active recovery, the recorded rate-pressure products during cardiac rehabilitation were most likely artificially low. Furthermore, the greater diastolic blood pressures (Figure 3) observed with lifting (as high as 138 mm Hg, but sel dom >126) suggest a possible benefit from increased myocardial perfusion pressure. We reiterate that this was without consequence and similar to responses previously reported. Thus, weight lifting, including maximal repetition lifting at high percent maximal contraction, appears to be a safe activity if properly supervised in this selected group of coronary patients.

Table I indicates the mean weight lifted and the maximal number of repetitions performed at each percent maximal contraction. The maximal number of repetitions performed in the 2-leg quadriceps extension was greater than that for any of the 1-arm lifts. This is most likely a result of increased muscular endurance in the legs due to a previous aerobic conditioning program that consisted primarily of walking and cycle ergometry.

There are several limitations to this study: First, noninvasive estimates of myocardial oxygen supply and demand were used. Although we cannot be certain that the results are valid, in the absence of ischemic signs and symptoms it appears reasonable to conclude that an appropriate myocardial oxygen supply-to-demand balance was maintained with weight lifting. Second, we do not know the extent to which the results of this study in clinically stable, aerobically trained patients with adequate ventricular function can be extrapolated to other populations of cardiac patients. Patients with more impaired ventricular function and those who were less conditioned may respond differently. Additional limitations include the relatively small number of patients, the ab-
sence of women, and the fact that all upper body lifts were 1-armed. More marked responses to upper body exercise may be seen in 2-arm exercise. Finally, additional studies using invasive techniques are warranted to further define cardiovascular responses to weight lifting.

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REFERENCES